ESRAD / EISCAT POLAR MESOSPHERE WINTER ECHOES DURING MAGIC AND ROMA

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ABSTRACT

Both ESRAD and the EISCAT VHF radars were operated during January 2005 covering the times of both the MAGIC and ROMA sounding rocket campaigns at Esrange and Andøya, respectively. Thin layers of enhanced radar echoes (PMWE) were observed on several occasions with ESRAD, and on one occasion with EISCAT. The PMWE show very high horizontal scatterer travel speeds and high aspect sensitivity (ESRAD), and spectral widths indistinguishable from those caused by the background plasma (EISCAT). We propose that scatter from highly-damped ion-acoustic waves generated by partial reflection of infrasonic waves provides a reasonable explanation of PMWE characteristics.

1. INTRODUCTION

Thin layers of enhanced radar echo from the winter high latitude mesosphere have been observed by many VHF radars both in Alaska and in Northern Scandinavia, since the first radars were deployed in the 1970s [1]. They have generally been assumed to be due to turbulence, but observations in recent years with the relatively low-power ESRAD radar (located at Esrange in northern Sweden) have shown that turbulence cannot explain many of the characteristics of the echoes and their origin is unclear. They are simply too strong to be explained by reasonable levels of turbulence [2], [3], [4], and they appear in conditions which would not allow active turbulence (monitored by meteorological rockets during the MacWAVE campaign in January 2003) [5],[6]. The echoes have been named Polar Mesosphere Winter Echoes, PMWE.

The MAGIC and ROMA sounding rocket campaigns from Esrange and Andøya, respectively, during January 2005 provided an opportunity to gather further information on PMWE, by both ground-based and rocket-borne instruments. This report concentrates on the results from the ESRAD 52 MHz radar at Esrange, Kiruna, and from the EISCAT VHF (224 Mhz) radar at Ramfjordmoen, Tromsø. The ESRAD radar ran continuously during most of January. EISCAT VHF radar observations were possible for only a few hours each day during the first part of the campaign period. The observation schedule and the results are summarized in Table 1. A solar proton event started on 15 January and continued until 23 January. ESRAD observed PMWE on each of these days, during daylight hours between about 8 – 16 UT. ESRAD also observed PMWE during the evening on 18 January. Before the start of the solar proton event, there were significant X-ray flares on 9 and 14 January, with PMWE observed by ESRAD also during the latter of these two dates. PMWE were also seen by ESRAD on 11 January, even though there were no significant solar proton or X-ray fluxes on this date. There was, however, high absorption recorded by riometer on this date so there was clearly an enhancement of D-region electron densities, probably due to precipitation of energetic electrons from within the magnetosphere. EISCAT operations were unfortunately confined to only a few hours each day and PMWE were seen on only one occasion, 17 January.

Fig. 1 illustrates the overall morphology of the PMWE observed by ESRAD, which is very similar to previously published results. PMWE have been found to be detectable with ESRAD on almost every day during solar proton events [2], and occasionally during other kinds of conditions of enhanced D-region electron densities [5],[6]. They are most often confined to the hours close to mid-day when the electron density is highest and the ratio of negative ions to electrons is expected to be low [2],[4]. PMWE appear between 50 km and 70 km heights, and often descend slowly over the course of the day. On a previous occasion when simultaneous wind profiling was available (from EISCAT VHF observations with a low-elevation radar beam) this slow descent was found to coincide with the phase progression of a strong inertio-gravity wave [4]. PMWE have occasionally been seen during night-time, but only at somewhat higher altitude, above 65 km [2],[7], as they are here seen on the evening of 18 January. To further compare the PMWE in January 2005 with previous observations we examine the strongest ESRAD PMWE and the EISCAT PMWE on 17 January in more detail in the next sections.

Table 1. ESRAD and EISCAT VHF observation schedule and related information during the MAGIC and ROMA campaigns in January 2005

date	ESRAD PMWE	EISCAT Obser-vations	EISCAT PMWE	Proton Flux[1]	X-ray Flux[2]	30 Mhz abs[3]
09	none			< 1	20	<0.5
10	none	10 - 14	none	< 1	< 1	<1.0
11	11 - 14			< 1	< 1	2.0
12	none	08 - 12	none	< 1	< 1	1.0
13	none	07–11,13-15	none	< 1	< 1	1.0
14	09 - 10	07-08,10-11	none	< 1	20	0.7
15	09 - 16			10	100	2.0
16	10 - 16			400	6	1.5
17	08 - 16	09-10,12-15	12-14	5000	400	2.5
18	08 –16 22 - 24	14-15	none	1000	40	4.0
19	08 - 16			100	200	2.0
20	08 - 16			1000	800	4.0
21	08 - 16			200	10	1.5
22	08 - 16			20	< 1	2.0
23	08 - 14			2	< 1	2.0
24	none			1	< 1	1.0
25	none			< 1	< 1	< 1.0

[1] particles cm^{-2} s^{-1} sr^{-1} energy > 10 Mev, maximum during 08-16 UT

[2] x10^{-6} Watts m^{-2}, 1-8 Å , maximum during 08-16 UT (both the above from GOES, http://www.sel.noaa.gov/ftpdir/plots/2005_plots/)

[3], dB, maximum cosmic noise absorbtion 08-16 UT at 30 Mhz (to within 0.5 dB) from the Abisko riometer (http://www.sgo.fi/Data/Riometer/)

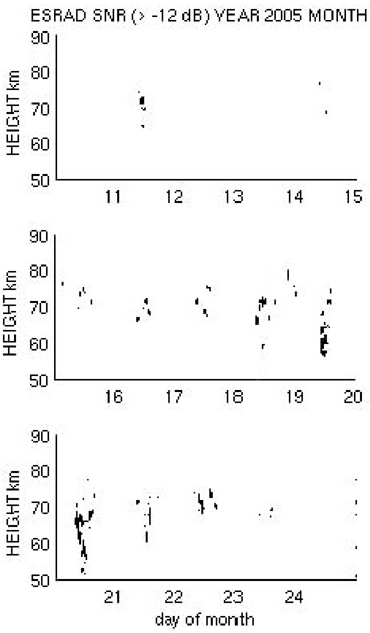

Fig. 1. Overview of PMWE observed by ESRAD between 10 and 24 January 2005. The black patches are PMWE.

2. ESRAD PMWE

It has been found, in a previous study of PMWE, that the scattering structures responsible for the radar echoes detected by ESRAD often have very high horizontal travel speeds [7], up to 500 m/s or more. Scatterers transported horizontally by the neutral wind would not be expected to travel faster than about 100 m/s. Such high speeds as 500 m/s exceed this by a wide margin and are comparable to (but higher than) the speed of sound, indicating that acoustic-gravity-wave propagation could be a major factor in controlling the horizontal motion of the radar scatterers. PMWE have further been found to be highly aspect sensitive with the signals coming only from angles very close to zenith, which might also be expected if wave phase-fronts rather than turbulence cause the scatter.

The technique used to determine horizontal scatterer velocity is ‘full correlation analysis’ [8]. The ESRAD antenna consists of an 18 x 16 array of 5-element yagis, spaced at about 4 meter intervals (0.7 x the radar wavelength). This array is divided into 6 sub-arrays, each with 6 x 8 yagis, with each sub-array connected to a separate receiver. The two-way half-power beam width for each segment is about 7° x 9°. During January 2005, 5 receivers were available and full correlation analysis was made by least square fitting to the cross- correlation functions formed between every available sub-array pair.

The results are shown in Fig. 2, for a representative selection of the strongest PMWE seen by ESRAD during January 2005. It is clear that horizontal travel speeds in excess of 100 m/s are seen on many occasions. It is also noteworthy that there is a large spread of speeds at each height, even though the time intervals plotted are rather short. There is no systematic relation between speed and height in these examples. This contrasts somewhat with results from November 2004 [7] where a tendency was found for the highest speeds to occur at the base of the PMWE layer, where the SNR was also highest. However, the PMWE seen during January 2005 were not as strong as those observed in November 2004.

Cross-spectral analysis in the frequency domain [9] can be used to determine the angular distribution of radar scattering regions within the antenna field of view. The result is a map of the direction of arrival of echoes corresponding to different parts of the frequency spectrum (different 'Doppler' frequencies) of the scattered signal. Representative results are shown in Fig. 3., which shows a pattern which has been found to be characteristic of PMWE [7]. Echoes come from a narrow 'streak' across the sky, which is about 1-2 ° in length and 0.5° or less in width. The Doppler frequency increases systematically from one end of the streak to the other. This is consistent with the concept of radar scatter from the phase-fronts of some kind of waves, moving across the field of view. It is not consistent with what is expected if turbulent eddies are responsible for the scatter. It is generally expected that turbulent vertical motion should cause the Doppler spreading of the spectrum in the latter case, and scattering regions corresponding to different turbulent velocities should be randomly distributed over the field of view.

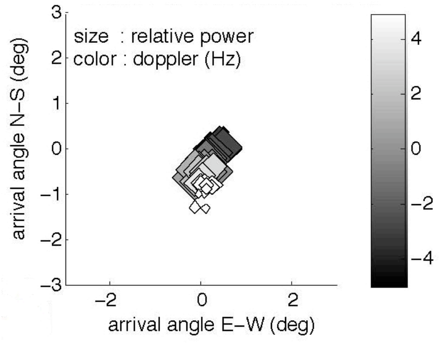

Fig. 3. Angle of arrival as a function of Doppler frequency of PMWE echoes seen by ESRAD at 2210-2215 UT on 18 January 2005, at 76.1 – 76.4 km height. Points are included for all Doppler shifts where the spectral power is at least half of the maximum for the whole spectrum.

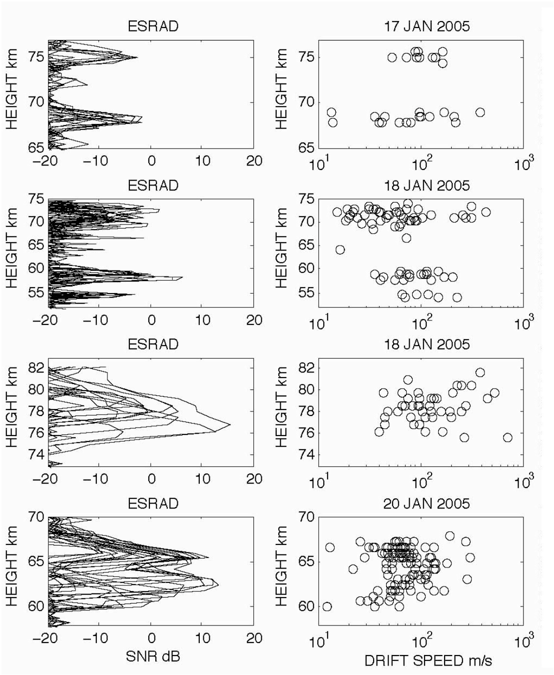

Fig. 2. Representative profiles through the PMWE layers on 17, 18 and 20 January, based on full correlation analysis of 6-minute averaged auto- and cross-correlations. Left-hand panels show height profiles of signal-to-noise ratio, right-hand panels show height profiles of horizontal scatterer drift speed.

3. EISCAT PMWE

The EISCAT VHF radar observed PMWE on one occasion, 17 January 2005. The radar was operating a program optimized for D-region observations, which is described in more detail in [7]. The antenna, which has a very narrow beam-width, about 0.6 x 1.2 degrees, was directed at 10 degrees away from zenith, towards the north. Spectra of the radar signal returns below, inside, and above the PMWE layer are shown in Fig. 4. A remarkable feature of these spectra is that there is no obvious difference in spectral width inside the PMWE layer and above and below it. This same behavior, with the same spectral width both inside and outside the PMWE, was also observed during the PMWE event in November 2004 [7] with the EISCAT antenna directed vertically. In that latter event, the PMWE spectral half-width varies between ca 7 Hz around mid-day and 20 Hz in the evening - the radar scatter from the background ionospheric plasma (the "ion-line" [10]), varies with time of day in just the same way. The changes in background spectral width might be expected due to an increase of negative ions in the evening. The similarity between PMWE and ion-line spectral widths points towards a common explanation.

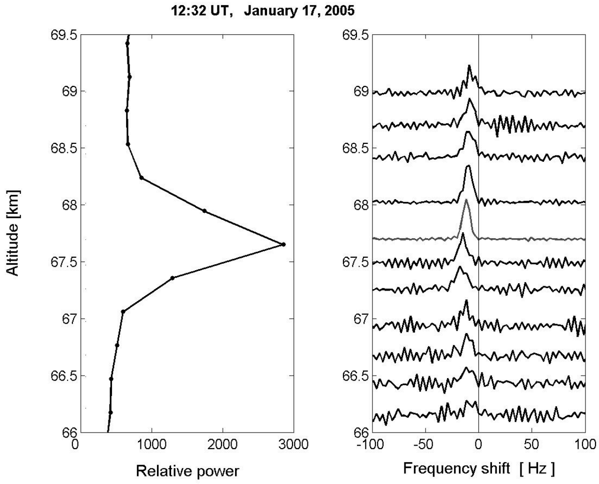

Figure 4. Scattered signal spectra measured by the EISCAT VHF radar, below, within and above the PMWE layer on 17 January 2005

4. DISCUSSION

A potential explanation for the characteristics of PMWE seems to be provided by the 'viscosity' or 'diffusion' waves which have been proposed earlier to explain VHF radar echoes in the lower stratosphere, MF radar echoes in the mesosphere, or VHF radar echoes at the summer mesopause [11],[12]. These are evanescent waves supposed to form at a (partially) reflecting boundary where gravity waves or acoustic waves are reflected by changes in temperature of wind speed. The waves which could cause radar scatter in the mesosphere are diffusion waves (i.e. governed by ion diffusion in the plasma). However these have the same wavelength and period characteristics as viscosity waves (which are in the neutral gas) when the ion diffusion and kinematic viscosity are equal, i.e. when the plasma is dominated by positive molecular ions and the ion-neutral collision frequency is high. When negative ions are present, the diffusivity is increased to higher values than the kinematic viscosity [13].

Fig. 5 illustrates the principles of the concept, while Fig. 6 provides calculations of the periods of gravity or acoustic waves needed to produce viscosity or diffusion waves with wavelengths matching the Bragg scale of ESRAD (ca 3m) and EISCAT VHF (ca 70 cm). The periods needed are in the range 0.1 – 10 s, i.e. in the region of infrasound. It is well known [14] that infrasound can reach the mesosphere (and even the lower thermosphere) with very little attenuation. It is also known that infrasound is often reflected back to Earth by gradients in propagation characteristics in this region. Both temperature gradients and wind shears can effectively reflect, or partially reflect, infrasound. Since the atmosphere is to a large extent horizontally stratified, the reflecting levels will generally lie close to horizontal and the diffusion wave-fronts will be close to horizontal.

In the case of the ESRAD radar, infrasound with periods of a few seconds and wavelengths of the order of a kilometer or more are needed to generate diffusion waves matching the 3 m Bragg scale. In this case, it is conceivable that one or a few diffusion-wave wave-fronts may be present in the field of view at any one time. They will lead to highly aspect sensitive echoes and will propagate across the field of view at the trace speed of the infrasound waves, which will be in excess of the speed of sound.

In the case of the EISCAT radar, infrasound of much shorter periods and wavelengths is needed to match the Bragg scale of 70 cm. In this case, there will generally be several diffusion waves in the field of view at any one time and they may be moving in many different directions. However, it should be noted that diffusion waves are the same waves which are responsible for the normal 'ion-line' radar scatter from the background plasma, also known as heavily damped ion-acoustic waves. In the background plasma, diffusion waves are generated by thermal fluctuations in the plasma. Although the excitation mechanisms are different in the background plasma and in the PMWE, the damping mechanisms can be the same, leading to the strong similarities in spectral width of the radar echoes.

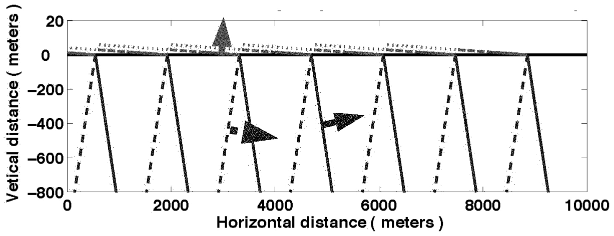

Fig. 5. Sketch showing the principles of evanescent viscosity or diffusion wave at a boundary where (partial) reflection of an infrasound wave occurs. The infrasound approaches from below and the evanescent wave forms immediately above the reflecting surface. The scales are appropriate for an evanescent wave matching the Bragg wavelength for the ESRAD radar. Note that the vertical distance scale is expanded above the reflecting level.

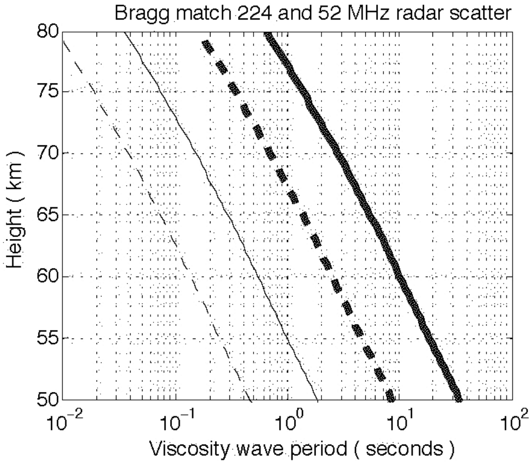

Fig. 6. Period of evanescent wave (= period of incident infrasonic wave) matching the wavelength for radar Bragg scattering as a function of height (based on kinematic viscosity calculated from the MSIS90E model). Solid lines are for viscosity waves or ion-diffusion waves in the case of only positive molecular ions. Dashed lines are for ion-diffusion waves with 3 times more negative ions than electrons. Thick lines are for Bragg matching to a 52 MHz radar , thin lines for a 224 MHz radar.

5. ACKNOWLEDGEMENTS

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